Fermilab

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Mu2e Project

Ron Ray
Mu2e Project Manager
4/11/15

Outline

- Introduction
- Project Status and Scope
- Evolution of Muon Program
- Management and Organization
- Laboratory Engagement
- University Engagement
- ESH&Q
- Schedule
- Progress over the past year
- Summary

Introduction

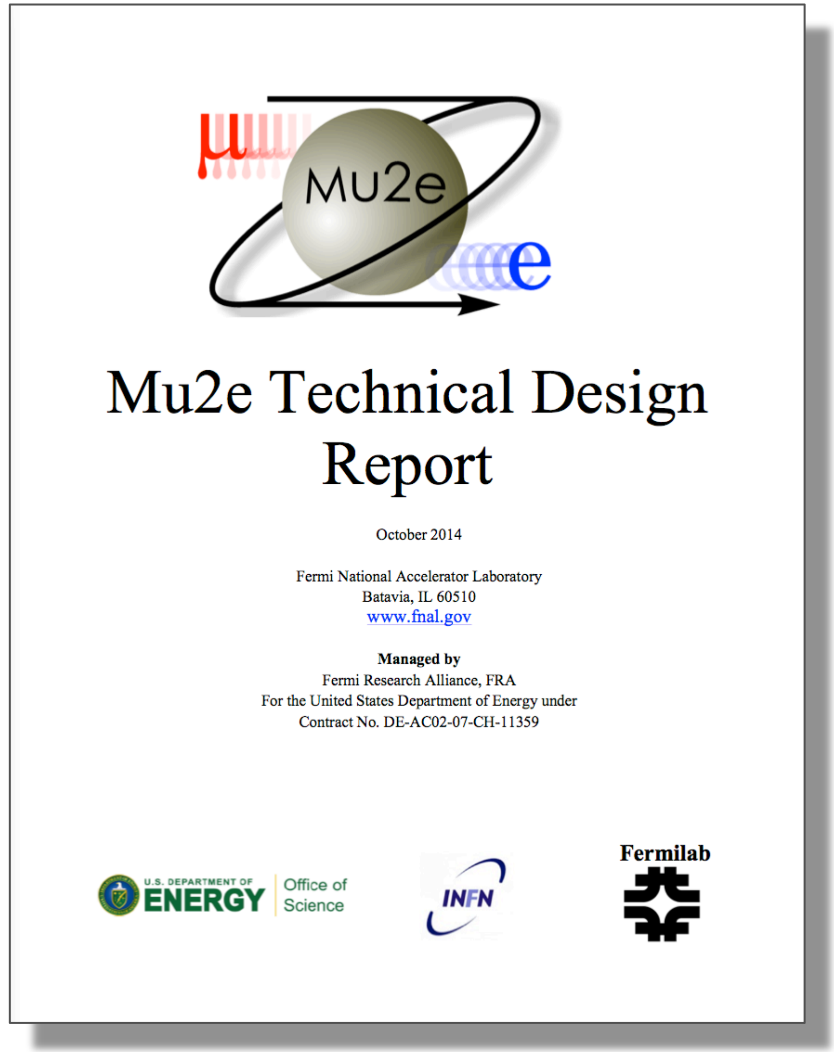
- Mu2e is a compelling discovery experiment with sensitivity to a broad range of new physics
  - Search for muon conversion to electron in the field of a nucleus
  - Reach extends to 10^4 TeV, beyond the reach of any current or planned accelerator.
  - Target sensitivity = ~3×10^{-17} (Requires 10^{18} stopped μ^- !).
  - Target background with full data set < 1 event.
- Synergistic part of the overall muon program at Fermilab.
- Full cost, schedule and risk analysis has been developed resulting in a Total Project Cost of $273.7M, matching the funding profile from OHEP.

Mu2e Project Status

- Mu2e received CD-0 in November, 2009
- CD-1 in July 2012
  - CD-1 cost range was $200 - $300M
- We received CD-3a approval to procure long-lead solenoid conductor in July 2014
  - ~$6M of procurements
- We have just completed a CD-2/3b follow-up review. ESAAB being scheduled for late Feb/early March
  - Total project cost of $273.7M
  - CD-2 for full project scope
  - CD-3b for Detector Hall and Transport Solenoid Modules
  - CD-3c for the balance of the project scheduled for mid-FY16
  - CD-4 scheduled for December 2020

Technical Design

- Technical design of Mu2e completed as part of CD-2 process.
- 888 page Technical Design Report includes physics justification, background studies, requirements and detailed technical design.
- Contributions from across all of Mu2e.



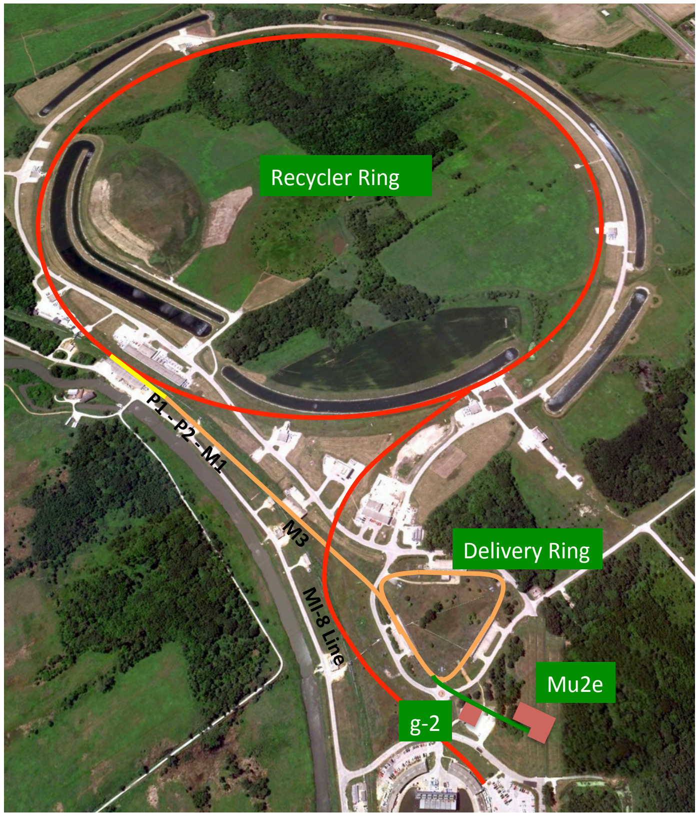
Mu2e Technical Design Report

October 2014

Fermi National Accelerator Laboratory
Batavia, IL 60510
www.fnal.gov

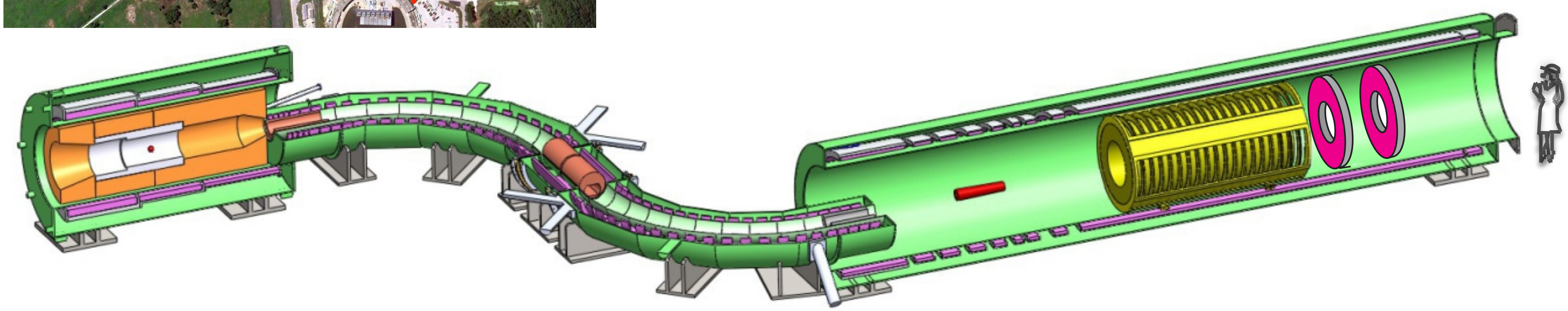
Managed by
Fermi Research Alliance, FRA
For the United States Department of Energy under
Contract No. DE-AC02-07-CH-11359

Mu2e Project Scope

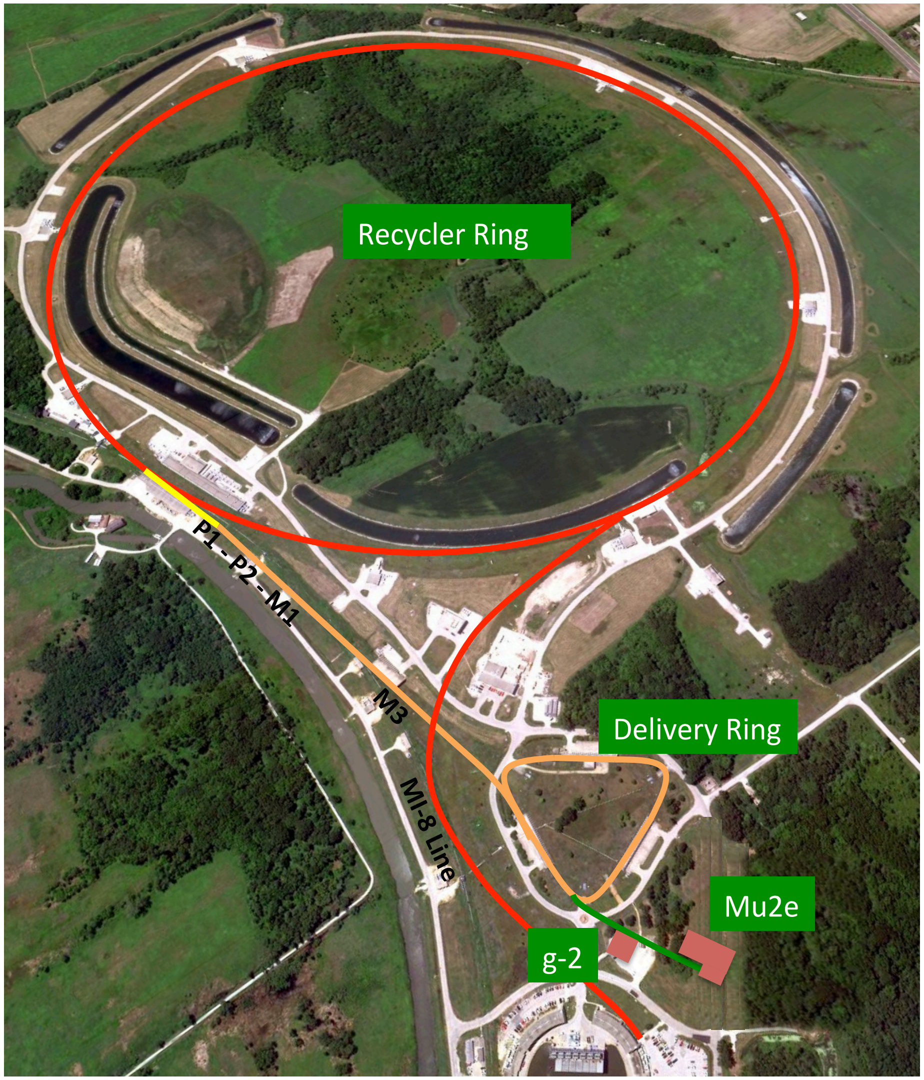


Mu2e Project scope includes

- New building to house experiment
- Modifications/additions to accelerator complex
- Mu2e apparatus
  - Superconducting Solenoids
  - Tracker
  - Calorimeter
  - Cosmic Ray Veto (not shown)
  - DAQ



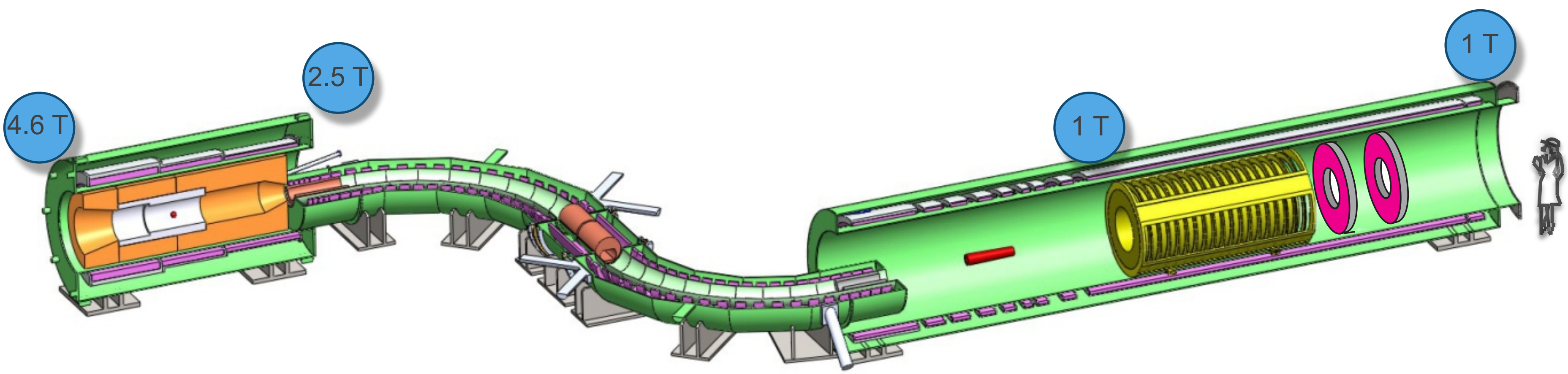
Beam Delivery



- We make muons by directing 8 GeV protons on to a target.
- Batches of protons from the Booster are transported through existing beamlines to the Recycler Ring where they are re-bunched and transported to the Delivery Ring through existing transport lines.
- Beam is slow extracted from Delivery Ring in microbunches of ~ 10^7 protons every 1694 ns through a new external beamline to the Mu2e production target.
- An *extinction system* removes residual protons between microbunches.
- Mu2e can run simultaneously with NOvA and Booster Neutrino Program.

Mu2e Apparatus

- Solenoids capture pions, form secondary muon beam, preserve timing structure, provide magnetic field for momentum analysis and help to reject backgrounds
  - Most efficient way of producing an intense, low energy muon beam



Mu2e Apparatus

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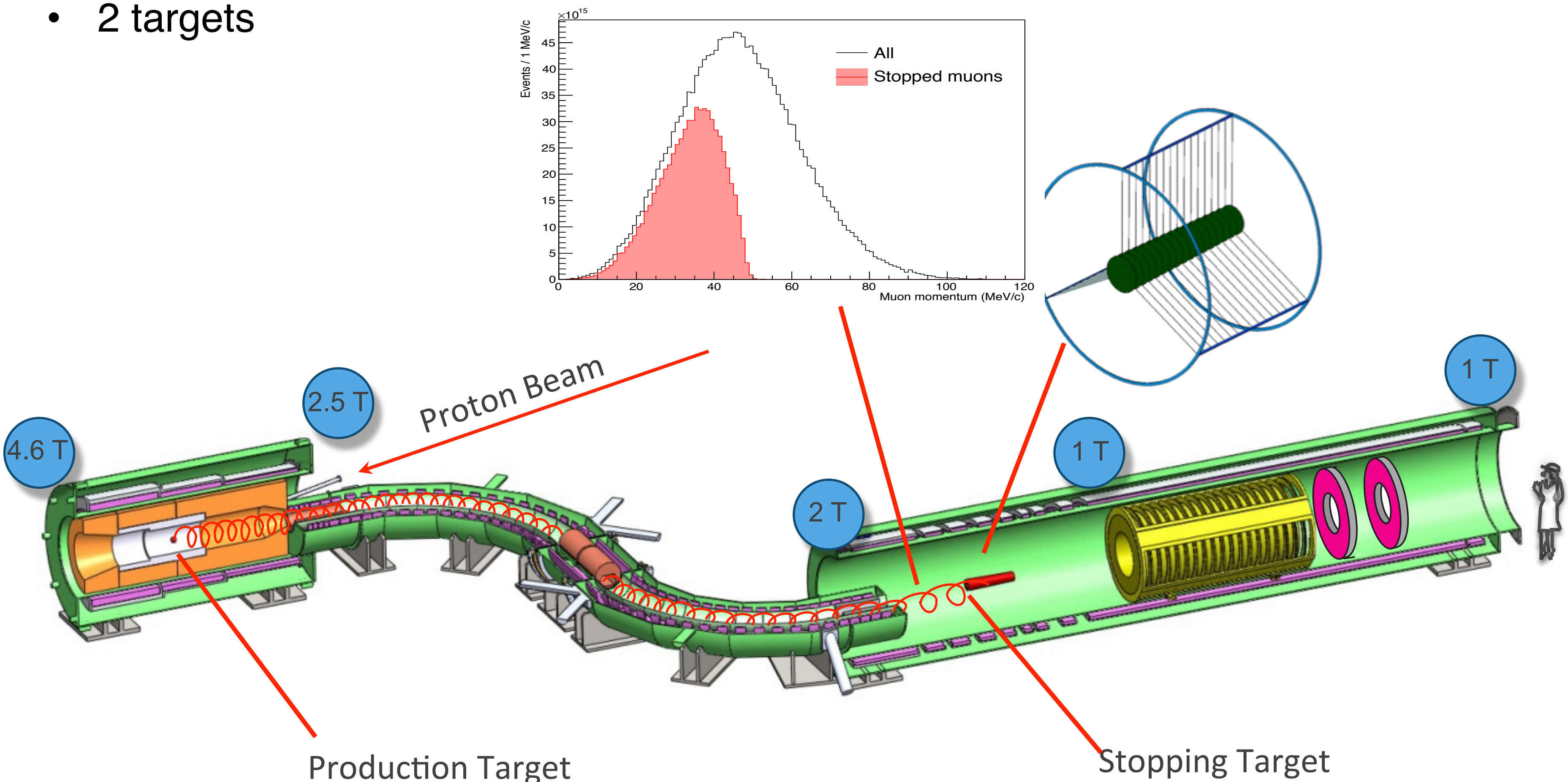
- 2 targets



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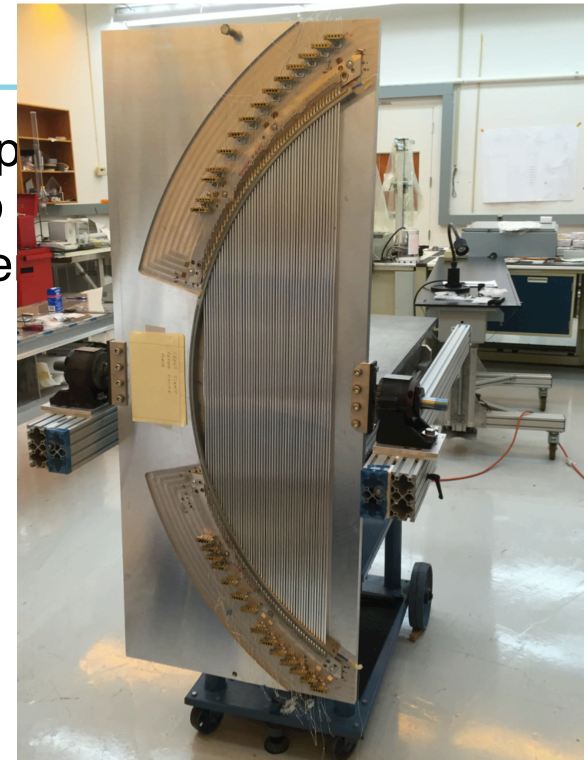

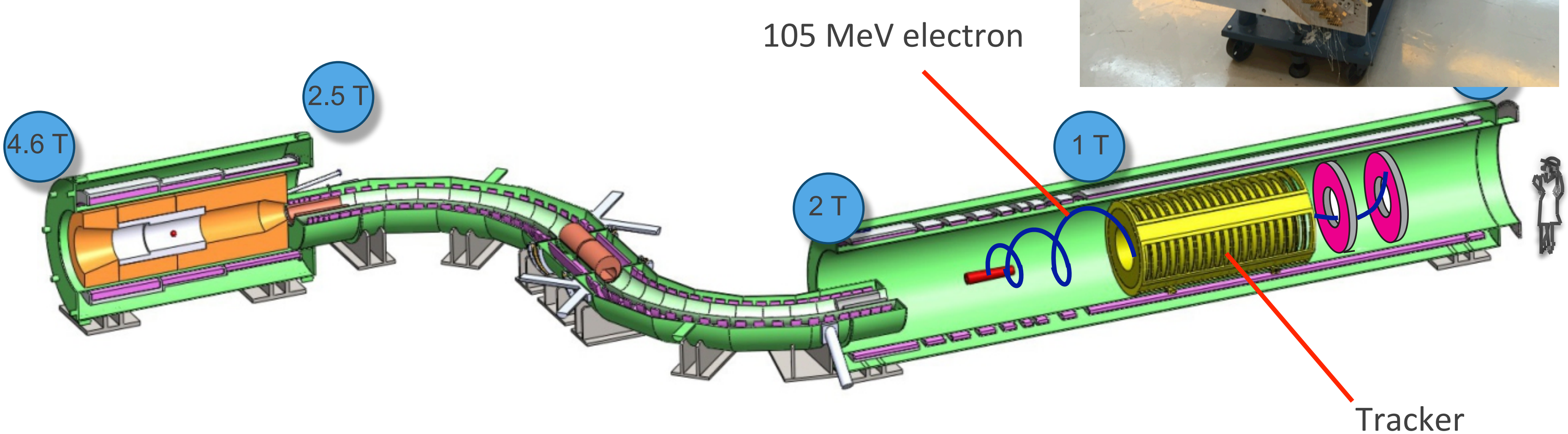

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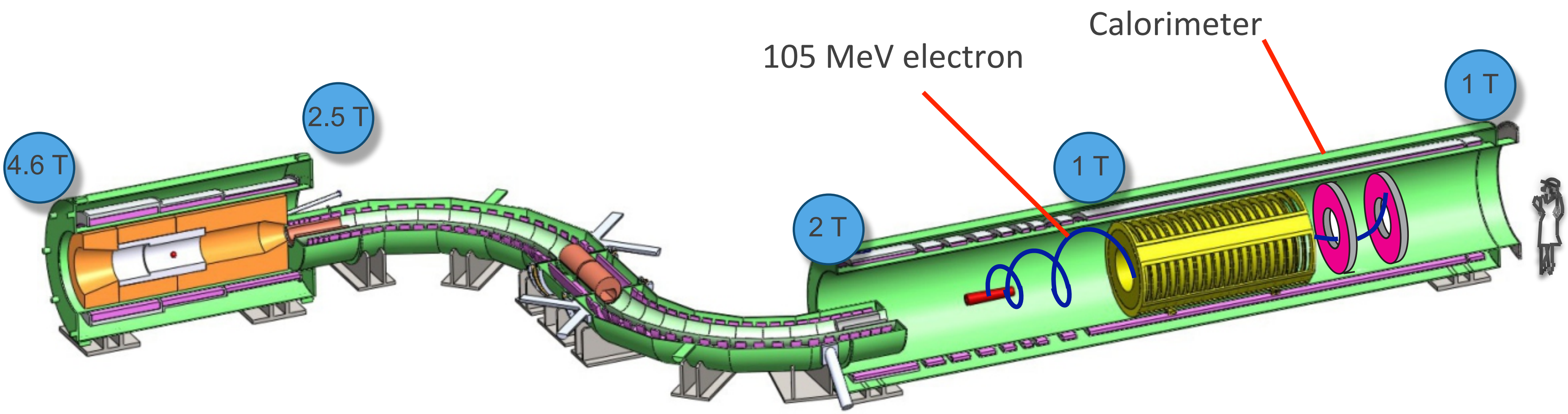

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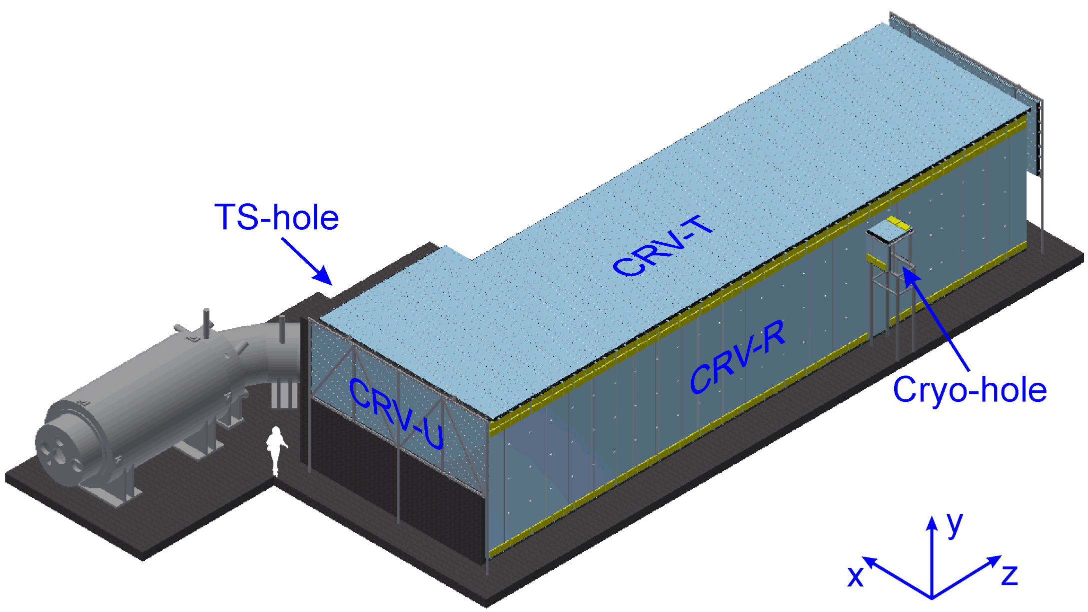
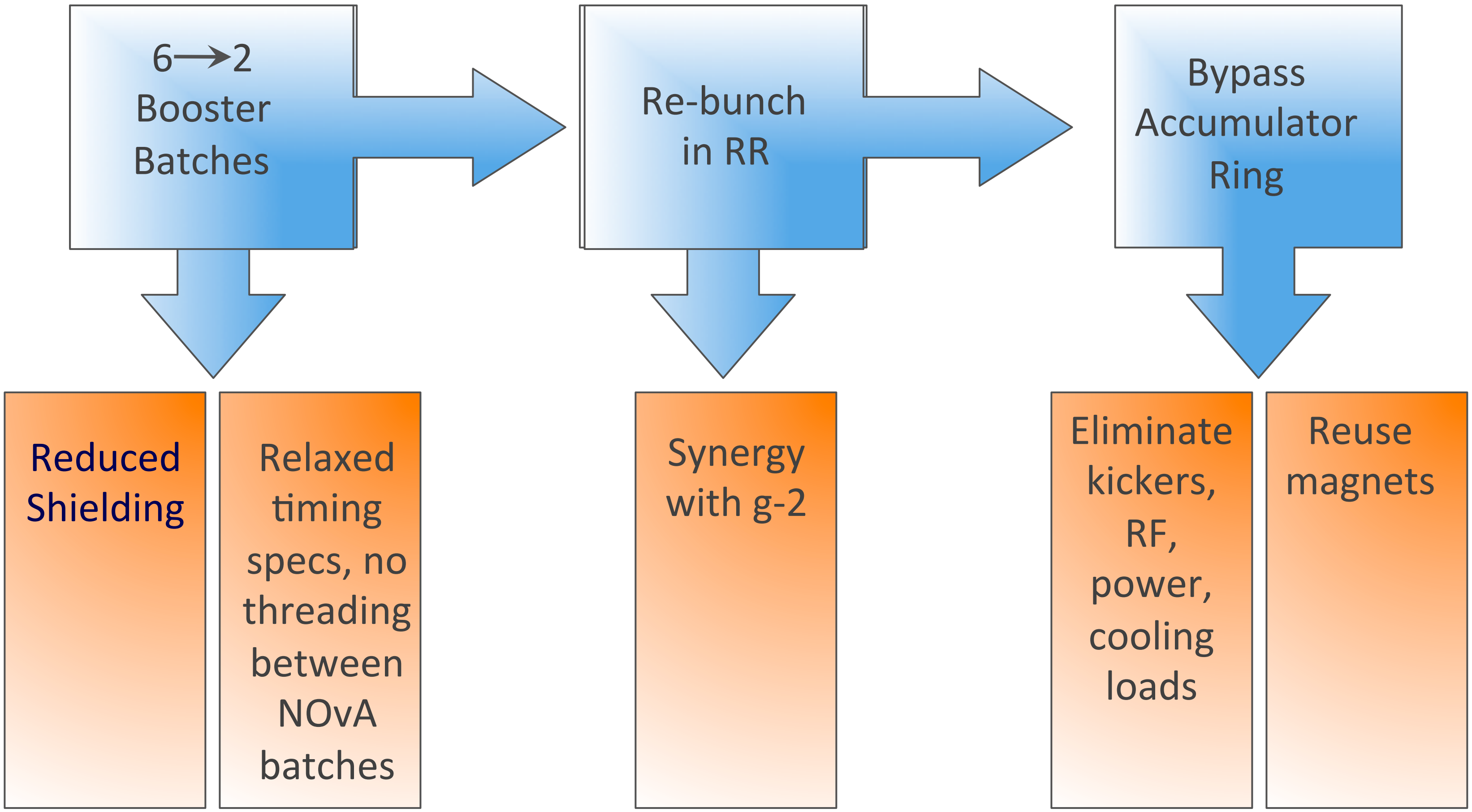
- Tracker – Straw tubes
- Calorimeter – BaF2 crystals
- Cosmic Ray Veto – Scintillator, WLS fibers, SiPMs



Evolution of Muon Program

- Mu2e and g-2 began as two distinct projects
- g-2 was located near A0
- Mu2e had a complicated and expensive plan for delivering 25 kW beam to the production target
  - Involved "threading" Mu2e Booster batches between NOvA batches in the Recycler
  - Re-bunching beam in the pbar Accumulator Ring
  - Slow extraction from Antiproton Debuncher Ring (renamed the Delivery Ring)
- Numerous technical challenges and incompatibilities between Mu2e and g-2.
- Muon Campus was born out the necessity to reduce the cost of Mu2e and solve incompatibilities between Mu2e and g-2.

Evolution of Mu2e – Descoping the Beam Power

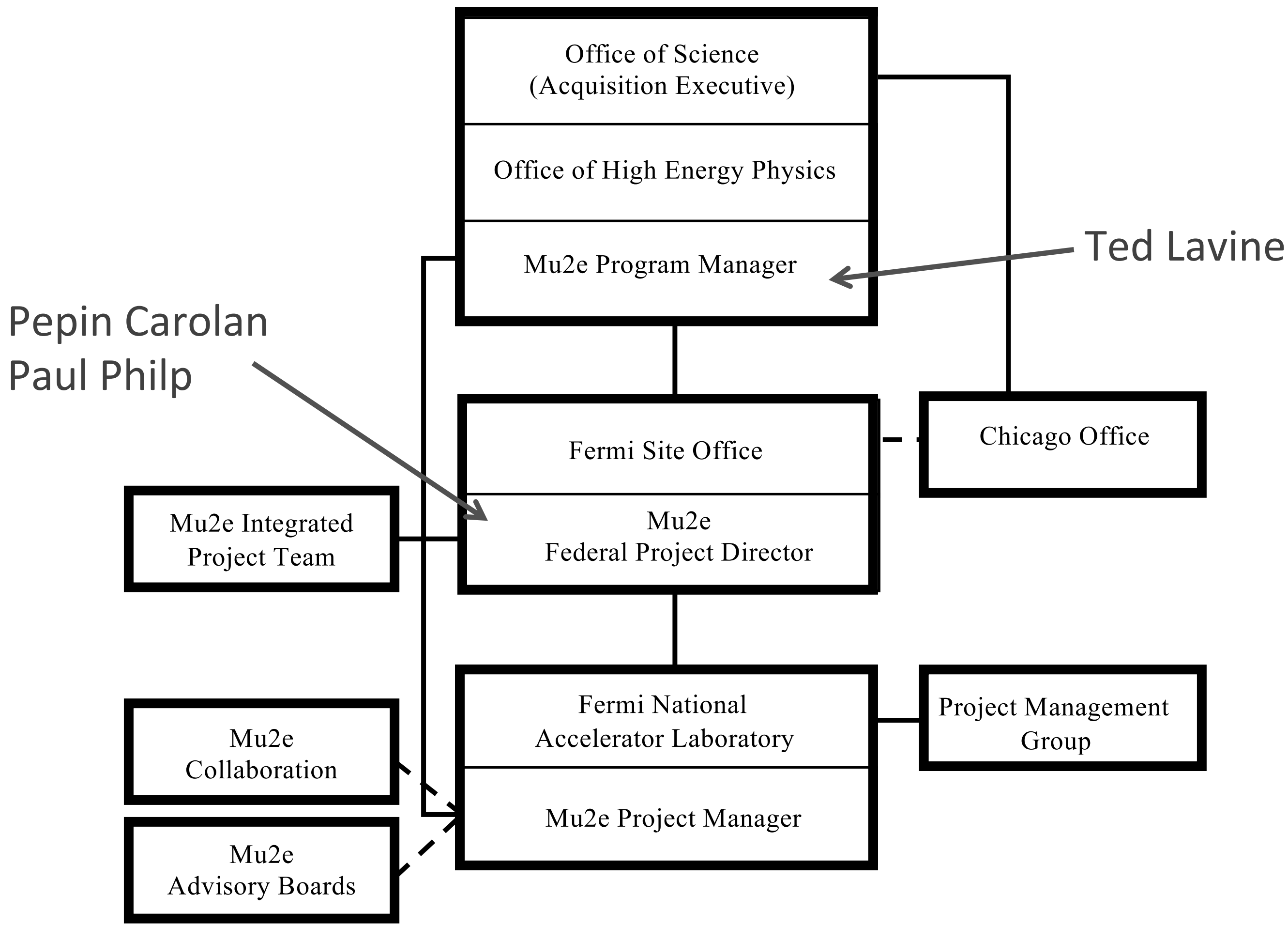


Synergies Between Mu2e and g-2

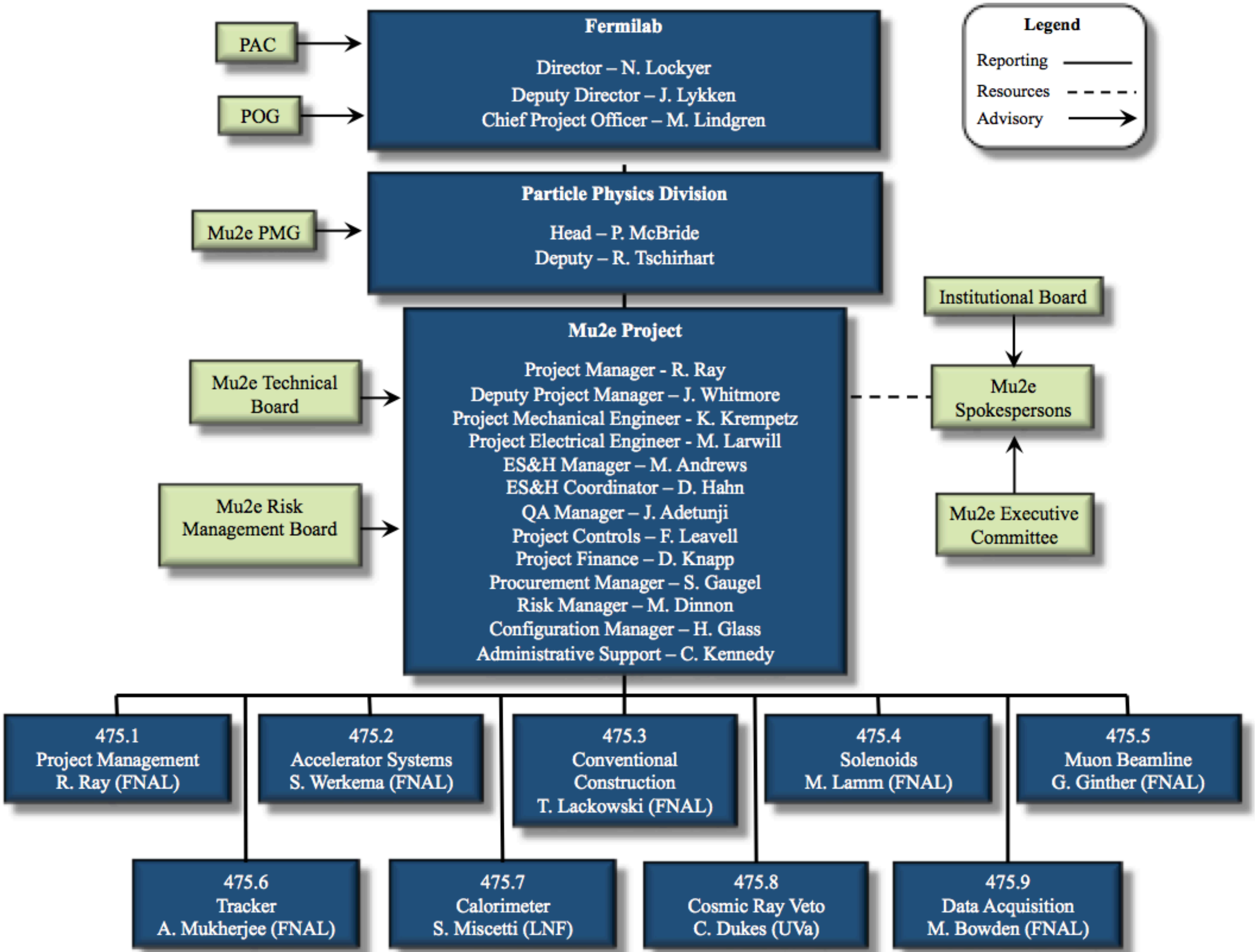
Move of g-2 to current location allowed for numerous synergies

- Common beamline
- Common Delivery Ring injection systems, instrumentation, abort dump
- Common Recycler Ring RF, injection and extraction systems.
- Common cryo plant located in MC-1 building
- Space for Mu2e power supplies in MC-1 building
- Common utilities, wastewater/stormwater handling
- The net result is two integrated world-class muon experiments for significantly less than the cost of the individual programs.
  - Growing, highly interactive muon community at Fermilab
  - Total is greater than the sum of the parts

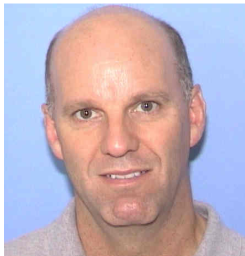
Mu2e Management and Organization



Management and Organization



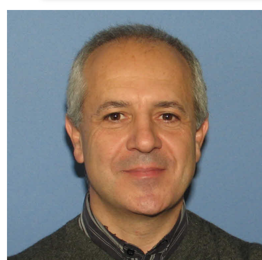
L2 Managers





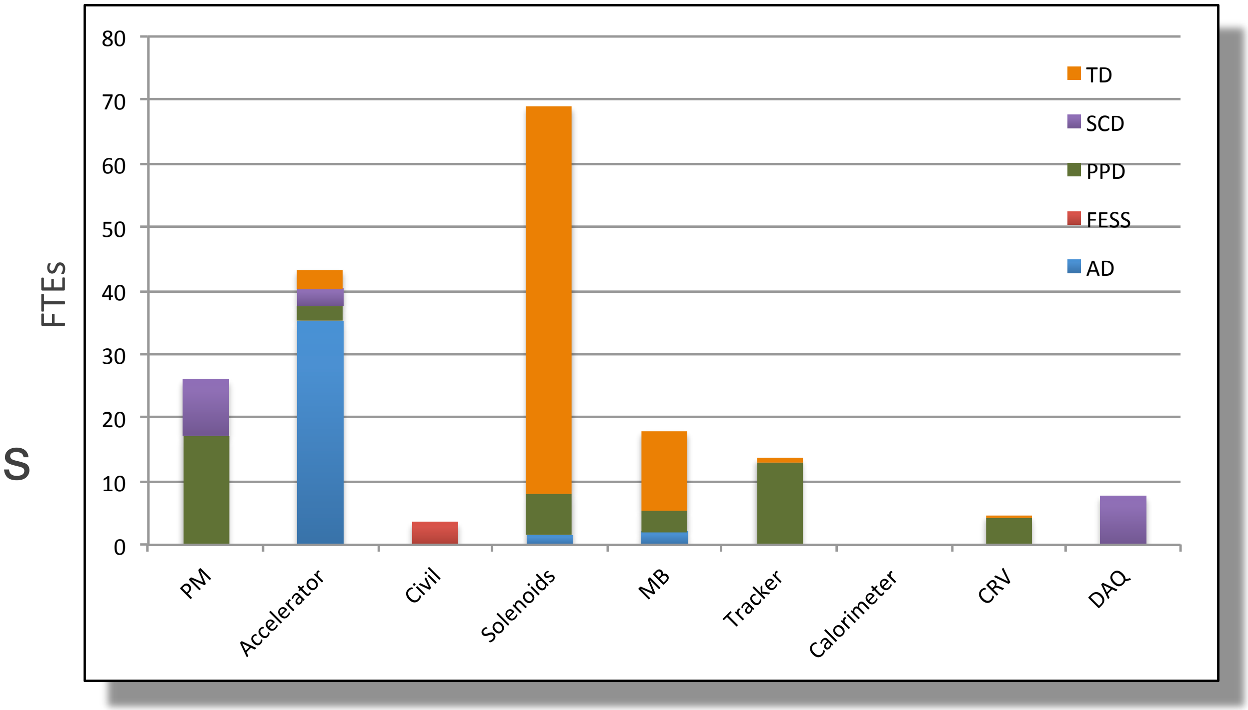
1	2	3	4	5
Project Management	**Accelerator**	**Conventional Construction**	**Solenoids**	**Muon Beamline**
R. Ray	S. Werkema	T. Lackowski	M. Lamm	G. Ginther
FNAL/PPD	FNAL/AD	FNAL/FESS	FNAL/TD	FNAL/TD

6	7	8	9
Tracker	**Calorimeter**	**Cosmic Ray Veto**	**Trigger and DAQ**
A. Mukherjee	S. Miscetti	C. Dukes	M. Bowden
FNAL/PPD	Frascati	UVa.	FNAL/CD

Laboratory Engagement

- Mu2e is a large, complex project requiring skillsets that are spread throughout the laboratory and university groups
- Significant Lab contributions from
  - AD
  - Computing
  - FESS
  - PPD
  - TD
  - Business Services
  - ES&H

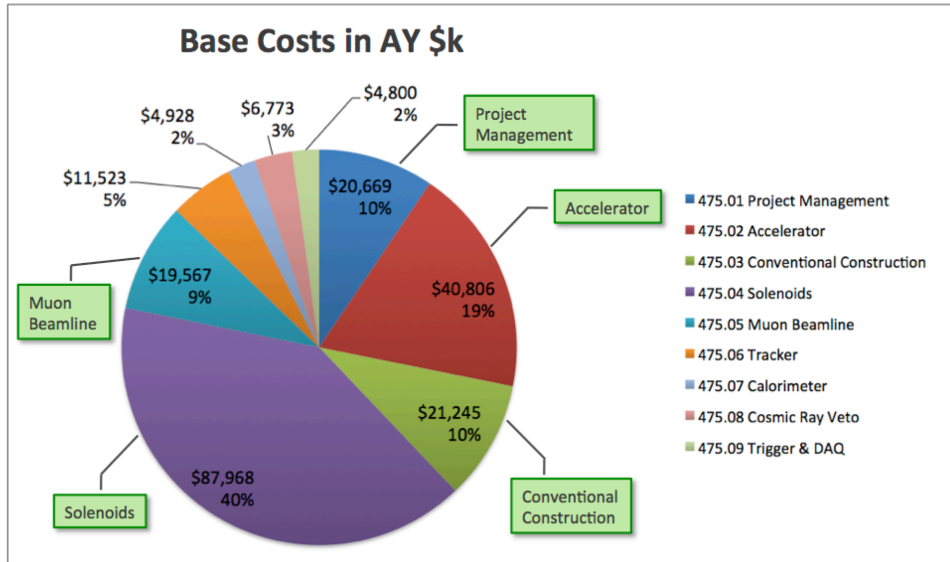


Laboratory Engagement

- Solenoids are centered in TD but there are significant contributions from PPD and AD
  – Cryo Engineering from PPD and AD
  – Mechanical FEA analysis from PPD
- Tracker is centered in PPD but significant engineering contributions from TD
- Muon Beamline is centered in TD but significant contributions from PPD and AD.
- Accelerator upgrades centered in AD
  – Significant TD contributions to extinction system, magnet construction
  – Pixel detector for Extinction Monitor centered in PPD

University Engagement

- Mu2e is frequently criticized as being Fermi-centric.
- Cost drivers are infrastructure and technical specialties
  - Solenoids, Accelerator upgrades, Civil Construction, Project Management.
    - Universities contribute to these activities, but main focus is on detectors.



- Cosmic Ray Veto – Led by UVA with significant contributions from NIU.
- Calorimeter – US effort led by Caltech (INFN also has significant responsibility)
- Tracker – Led by Fermilab with significant contributions from Rice, Berkeley, LBNL, Houston, Duke, York, Minnesota, Argonne.
- Extinction Monitor – Led by Fermilab, significant contributions from Purdue, NIU, Rice.
- Stopping Target Monitor – Led by Boston University

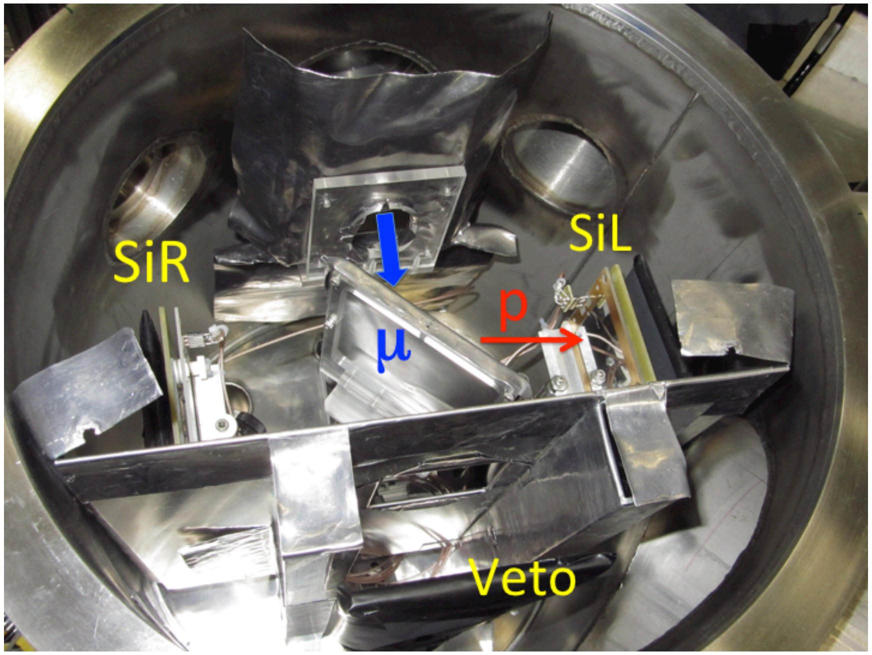
Project Positions Held by Collaboration Colleagues

- C. Wang (Duke) Straws L3
- M. Corcoran (Rice) Straw Assemblies L3
- D. Ambrose (Minnesota) Tracker Panel Prototype Assembly L4
- E. Hungerford (Houston) Tracker readout Controller L4
- D. Brown (LBNL) Tracker Electronics Test L4
- J. Popp (York) Tracker straw QC L4
- D. Hitlin (Caltech) Calorimeter Deputy L2, Crystals L3
- R.Y. Zhu (Caltech) Calorimeter Crystal Characterization
- F. Happacher (INFN-Frascati) Calorimeter Mechanics L3
- F. Spinella (Pisa) Calorimeter Digitizer
- G. Corradi (INFN-Frascati) Calorimeter FEE
- I. Sarra (INFN Frascati) Calorimeter Photosensors
- F. Porter (Caltech) Calorimeter Calibration L3
- A Saputi (INFN-Frascati) Calorimeter Assembly and Installation L3
- C. Dukes (Virginia) CRV L2
- G. Blazey (NIU) CRV Photosensor L3
- Y. Oksuzian (Virginia) CRV Fibers L3
- C. Group (Virginia/FNAL) CRV Module Fabrication L3
- Vinny Polychronakos (BNL) CSC CRV Test Stand L4
- J. Miller (BU) Stopping target L3, Stopping Target Monitor L3
- D. Hedin (NIU) Muon Beam Stop L3
- M. Jones (Purdue) Extinction Monitor DAQ L4
- P. Fabbricatore (INFN-Genoa) Solenoid Conductor QC L4
- P. Winter (ANL) Solenoid Field Measurement L3

University community also plays significant roles in the Collaboration – cf. K. Knoepfel, Breakout Session 6B

University Engagement

- Collaboration heavily involved in simulation efforts.
  - Implementation of art framework for Mu2e.
  - Development of requirements and specifications
  - Background simulations
  - Calibration techniques
  - Neutron task force
- Collaboration heavily involved in prototype and test beam efforts
  - Tracker plane test in vacuum
  - Calorimeter beam tests
  - Cosmic ray veto beam tests and cosmic ray test stand
  - AlCap beam test to measure proton spectrum from stopping μ^- in aluminum.



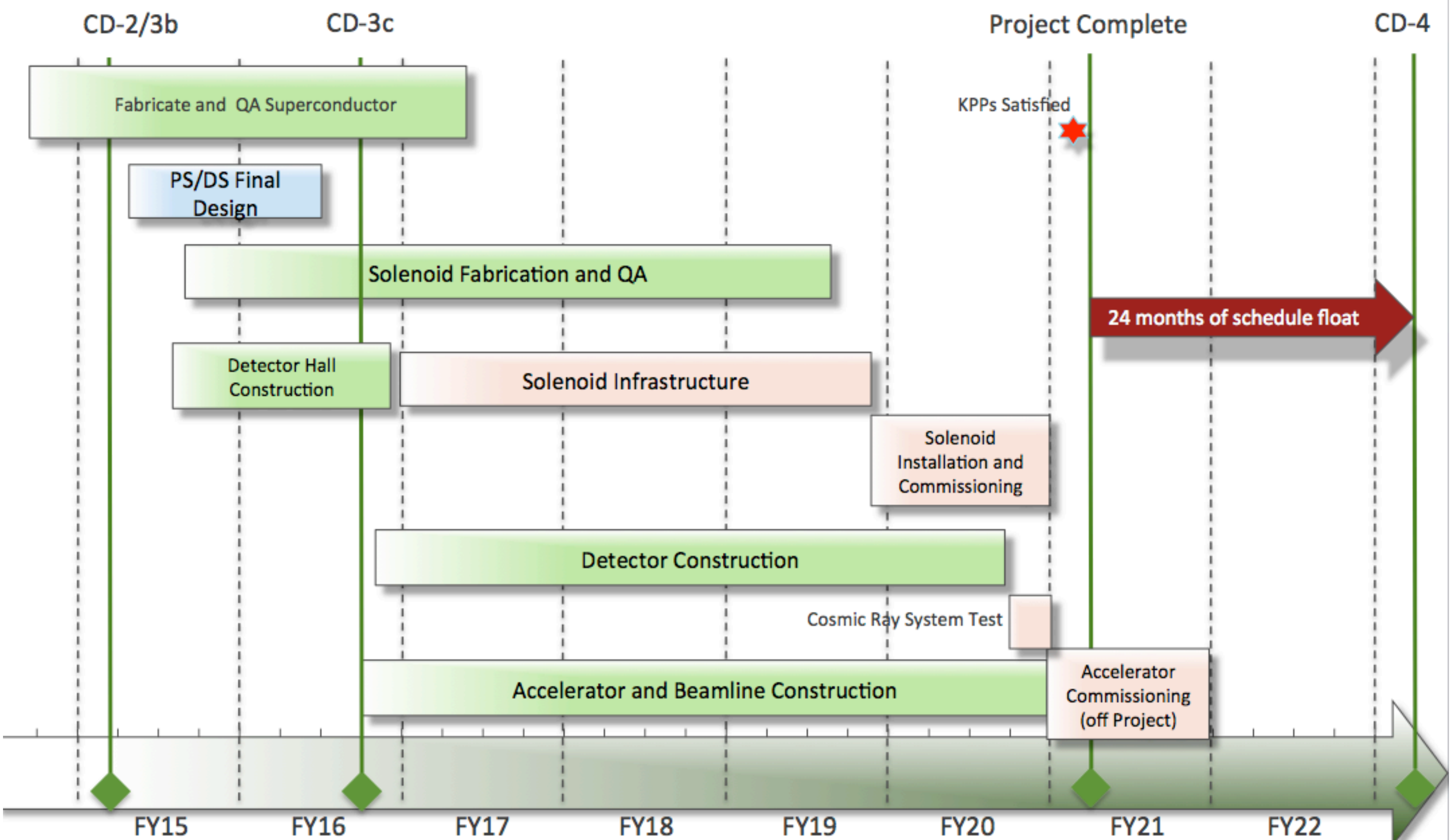
Project-Collaboration Engagement

- Project-Collaboration cooperation necessary for success
  - Collaboration provides many resources to the Project
  - Project will deliver a working apparatus to the Collaboration to do the physics
- The Collaboration is engaged in defining the Project scope
  - Requirements definition and documentation
  - Downselect recommendations
  - Simulations
  - Participation in Project Technical Board, Risk Management Board, Project Management Group and Integrated Project Team meetings.
- Good communication between project/Collaboration leadership

ESH&Q

- Fermilab and Mu2e Project firmly committed to safety and quality.
- Safety and Quality integrated into Lab management at all levels.
- Oversight by Lab ESH&Q organization as well as by Division & Section ES&H organizations
- Project ES&H Manager – Mike Andrews
- Project ES&H Coordinator – Dee Hahn
- Project QA Manager – Jemila Adetunji
- Integrated Safety Management Plan developed
- Hazard Analysis Report including evaluation and mitigation of safety risks developed
- Quality Assurance Program developed
- NEPA approval obtained in 2012.
- Preliminary Shielding Assessment approval
- Preliminary approval of Total Loss Monitors (TLM) as a credited safety system

Schedule


CD-2/3b
CD-3c
Project Complete
CD-4
Fabricate and QA Superconductor
KPPs Satisfied
PS/DS Final Design
Solenoid Fabrication and QA
24 months of schedule float
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
Detector Construction
Cosmic Ray System Test
Accelerator and Beamline Construction
Accelerator Commissioning (off Project)
FY15
FY16
FY17
FY18
FY19
FY20
FY21
FY22

Progress Over the Past Year

- Completion of Preliminary Design for CD-2, TDR, CD-2 reviews and anticipated CD-2 signoff in a few weeks.
- Completion of solenoid conductor R&D, CD-3a approval and initiation of conductor fabrication.
- Completion of solenoid reference designs, placement of contract with General Atomics for final design and fabrication of PS and DS.
- Final designs completed for Detector Hall and TS Modules
  - CD-3b approval expected in a few weeks. Will begin construction on Detector Hall ASAP.
- Full hit-level simulation of experiment and evaluation of backgrounds and sensitivity for TDR.

Summary

- Significant progress over the past year
  - Mu2e enjoys strong support from across all of Fermilab
  - Collaborating institutions make significant contributions to simulations that validate designs, to detector R&D, test beam efforts and project execution.
- Rapid progress expected to continue
  - CD-2 and CD-3b approval expected soon (early March)
  - Ground breaking for Detector Hall (March)
  - Solenoid conductor approved by CD-3a will begin arriving this summer
  - Begin Fabricating TS Modules in April
  - Finalize PS/DS designs
  - Detector prototypes to validate final designs
- CD-3c expected in mid-FY16 to authorize construction across whole Project
- Commissioning with beam to begin in 2020.

Backup Slides

KPPs

Key Parameters	Threshold Performance	Objective Performance	Comments
Accelerator	Accelerator components are acceptance tested at nominal voltages and currents. Components necessary for single-turn extraction installed.	Protons are delivered to the diagnostic absorber in the M4 beamline.	Delivery of beam is beyond the control of the Project, so it must be an Objective parameter. In addition, there are various program planning issues associated with g-2 running and accelerator shutdowns that impact delivery of beam to Mu2e.
	Shielding designed for 1.5 kW operation delivered to Fermilab and ready for installation.	Shielding designed for 8 kW operation delivered to Fermilab and ready for installation.	Running at 1.5 kW eliminates the need for heavy concrete shielding.
	All target station components are complete, delivered to Fermilab and tested. Heat and Radiation Shield is installed in Production Solenoid. Other components are ready to be installed after field mapping.		
Superconducting Solenoids	The Production, Transport and Detector Solenoids have been cooled and powered to the settings necessary to take physics data.	The Production, Transport and Detector Solenoids have been cooled and powered to nominal field settings.	The threshold parameter is adequate to take physics data, though perhaps not fully optimized.
Detector Components	Cosmic ray tracks are observed in the Tracker, Calorimeter and a subset of the Cosmic Ray Veto and acquired by the Data Acquisition System after they are installed in the garage position behind the DS. The balance of the CRV counters are at Fermilab and ready for installation.	The cosmic ray data in the detectors is acquired by the Data Acquisition System, reconstructed in the online processors, visualized in the event display and stored on disk.	Online reconstruction algorithms are designed for spiraling tracks while cosmic rays are straight. May require some specialized code. Work done by uncosted scientists. The Cosmic Ray Veto is installed off project after all field mapping is complete. Only a few modules would be used to satisfy the KPPs.

Objective KPPs assume that Threshold KPPs have been met.